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UNITED STATES PATENT APPLICATION

of

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for

BRAZED DIAMOND TOOLS AND METHODS FOR MAKING THE SAME

TO THE COMMISSIONER OF PATENTS AND TRADEMARKS:

Your petitioner, Chien-Min Sung, citizen of the United States and resident of Taipei County, Taiwan, whose residence and postal mailing address is No. 4, Lane 32, Chung-cheng Rd., Tansui, Taipei County, Taiwan, prays that letters patent may be granted to him as the inventor of a **BRAZED DIAMOND TOOLS AND METHODS FOR MAKING THE SAME** as set forth in the following specification.

PRIORITY INFORMATION

This application is a continuation-in-part of United States Patent Application Serial No. 09/935,204, filed August 22, 2001, which is a continuation-in-part of United States Patent Application Serial No. 09/399,573, filed September 20, 1999, now issued as United States Patent No. 6,286,498, which is a continuation-in-part application of United States Patent Application Serial No. 08/835,117, filed April 4, 1997, now issued as United States Patent No. 6,039,641, and of United States Patent Application Serial No. 08/832,852, filed April 4, 1997, now abandoned, all of which are incorporated herein by reference.

This patent application is also a continuation-in-part of United States Patent Application Serial No. 10/109,531 filed March 27, 2002, which is a continuation-in-part of United States Patent Application Serial No. 09/588,582 filed April 26, 2000, now issued as United States Patent No. 6,368,198, which is a continuation-in-part of United States Patent Application Serial No. 09/447,620 filed November 22, 1999, now abandoned, all of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to tools having diamond particles chemically bonded to a matrix support material, or a substrate, and arranged in a predetermined pattern. Accordingly, the present invention involves the fields of chemistry, metallurgy, and materials science.

BACKGROUND OF THE INVENTION

Abrasive tools have long been used in numerous applications, including cutting, drilling, sawing, grinding, lapping and polishing of materials. Because diamond is the hardest abrasive material currently known, it is widely used as a superabrasive on saws, drills, and other devices, which utilize the abrasive to cut, form, or polish other hard materials.

Diamond tools are particularly indispensable for applications where other tools lack the hardness and durability to be commercially practical. For example, in the stone industry, where rocks are cut, drilled, and sawed, diamond tools are about the only tools that are sufficiently hard and durable to make the cutting, etc., economical. If diamond tools were not used, many such industries would be

economically infeasible. Likewise, in the precision grinding industry, diamond tools, due to their superior wear resistance, are uniquely capable of developing the tight tolerances required, while simultaneously withstanding wear sufficiently to be practical.

A typical superabrasive tool, such as a diamond saw blade, is manufactured by mixing diamond particles (e.g., 40/50 U.S. mesh saw grit) with a suitable metal support matrix powder (e.g., cobalt powder of 1.5 micrometer in size). The mixture is then compressed in a mold to form the right shape (e.g., a saw segment). This "green" form of the tool is then consolidated by sintering at a temperature between 700-1200 °C to form a single body with a plurality of abrasive particles disposed therein. Finally, the consolidated body is attached (e.g., by traditional brazing or soldering) to a tool body; such as the round blade of a saw, to form the final product.

Despite their prevailing use, diamond tools generally suffer from several significant limitations, which place unnecessary limits on their useful life. For example, the abrasive diamond or cubic boron nitride (CBN) particles are not distributed uniformly in the matrix that holds them in place. As a result, the abrasive particles are not positioned to maximize efficiency for cutting, drilling, grinding, polishing, etc.

The distance between diamond or CBN abrasive particles determines the work load each particle will perform. Improper spacing of the diamond or CBN abrasive particles typically leads to premature failure of the abrasive surface or structure. Thus, if the diamond/CBN abrasive particles are too close to one another, some of the particles are redundant and provide little or no assistance in cutting or grinding. In addition, excess particles add to the expense of production due the high cost of diamond and cubic boron nitride. Moreover, these non-performing diamond or CBN particles can block the passage of debris, thereby reducing the cutting efficiency. Thus, having abrasive particles disposed too close to one another adds to the cost, while decreasing the useful life of the tool.

On the other hand, if abrasive particles are spaced too far apart, the workload (e.g., the impact force exerted by the work piece) for each particle becomes excessive. The sparsely distributed diamond or CBN abrasive particles may be crushed, or even dislodged from the matrix into which they are disposed. The damaged or missing abrasive particles are unable to fully assist in the workload. Thus, the workload is

transferred to the surviving abrasive particles. The failure of each abrasive particle causes a chain reaction which soon renders the tool ineffective to cut, drill, grind, etc.

Different applications may require different size of diamond (or cubic boron nitride) abrasive particles. For example, drilling and sawing applications may require a large sized (20 to 60 U.S. mesh) diamond grit to be used in the final tool. The metal substrate of the tool is typically selected from cobalt, nickel, iron, copper, bronze, alloys thereof, and/or mixtures thereof. For grinding applications, a small sized (60/400 U.S. mesh) diamond grit (or cubic boron nitride) is mixed with either metal (typically bronze), ceramic/glass (typically a mixture of oxides of sodium, potassium, silicon, and aluminum) or resin (typically phenolic).

Often the tool may include a matrix support material, such as a metal powder, which holds or supports the diamond particles. However, because diamond or cubic boron nitride is much larger than the matrix powder (300 times in the above example for making saw segments), and it is much lighter than the latter (about 1/3 in density for making saw segments), it is very difficult to mix the two to achieve uniformity. Moreover, even when the mixing is thorough, diamond particles can still segregate from metal powder in the subsequent treatments such as pouring the mixture into a mold, or when the mixture is subjected to vibration. The distribution problem is particularly troublesome for making diamond tools when diamond is mixed in the metal support matrix.

There is yet another limitation associated with the many methods of positioning diamond grits in a tool. Many times a metal bond diamond tool requires different sizes of diamond grits and/or different diamond concentrations to be disposed at different parts of the same diamond tool. For example, saw segments tend to wear faster on the edge or front than the middle. Therefore, higher concentrations and smaller diamond grit are preferred in these locations to prevent uneven wear and thus premature failure of the saw segment. These higher concentration/smaller size segments (i.e. "sandwich" segments) are difficult to fabricate by mixing diamond particles with metal powder. Thus, despite the known advantages of having varied diamond grit sizes and concentration levels, such configurations are seldom used because of the lack of a practical method of making thereof.

Another drawback of many diamond tools is that the abrasive particles, or "grits" are insufficiently attached to the tool substrate, or matrix support material, to

maximize useful life of the cutting, drilling, polishing, etc., body. In fact, in most cases, diamond grits are merely mechanically embedded in the matrix support material. As a result, diamond grits are often knocked off or pulled out prematurely. Moreover, the grit may receive inadequate mechanical support from the loosely bonded matrix under work conditions. Hence, the diamond particles may be shattered by the impact of the tool against the workpiece to which the abrasive is applied.

It has been estimated that, in a typical diamond tool, less than about one tenth of the grit is actually consumed in the intended application (i.e. during actual cutting, drilling, polishing, etc). The remainder is wasted by either being leftover when the tool's useful life has expired, or by being pulled-out or broken during use due to poor attachment and inadequate support. Most of these diamond losses could be avoided if the diamond particles can be properly positioned in and firmly attached to the surrounding matrix.

In order to maximize the mechanical hold on the diamond grits, they are generally buried deep in the substrate matrix. As a result, the protrusion of the diamond particles above the tool surface is generally less than desirable. Low grit protrusion limits the cutting height for breaking the material to be cut. As a result, friction increases and limits the cutting speed and life of the cutting tool.

In order to anchor diamond grit firmly in the support matrix, it is highly desirable for the matrix to form carbide around the surface of the diamond. The chemical bond so formed is much stronger than the traditional mechanical attachment. The carbide may be formed by reacting diamond with suitable carbide formers such as a transition metal. Typical carbide forming transition metals are: titanium (Ti), vanadium (V), chromium (Cr), zirconium (Zr), molybdenum (Mo), and tungsten (W).

The formation of carbide requires that the carbide former be deposited around the diamond and that the two subsequently be caused to react to form carbide. Moreover, the non-reacted carbide former must also be consolidated by sintering or other means. All these steps require treatment at high temperatures. However, diamond may be degraded when exposed to a temperature above about 1,000° C. The degradation is due to either the reaction with the matrix material or the development of micro-cracks around metal inclusions inside the crystal. These inclusions are often trapped catalysts used in the formation of synthetic diamond.

Most carbide formers are refractory metals so they may not be consolidated below a temperature of about 1,200° C. Hence, refractory carbide formers are not suitable as the main constituent of the matrix support material.

There are, however, some carbide formers that may have a lower melting temperature, such as manganese (Mn), iron (Fe), silicon (Si), and aluminum (Al). However, these carbide formers may have other undesirable properties that prohibit them from being used as the primary constituent of the matrix support material. For example, both manganese and iron are used as catalysts for synthesizing diamond at high pressure (above 50 Kb). Hence, they can catalyze diamond back to graphite during the sintering of the matrix powder at a lower pressure. The back conversion is the main cause of diamond degradation at high temperature.

Aluminum, on the other hand, has a low melting point (660° C), thus, making it easy to work with for securing the diamond particles. However, the melting point of aluminum can be approached when diamond grit is cutting aggressively. Hence, aluminum may become too soft to support the diamond grit during the cutting operation. Moreover, aluminum tends to form the carbide Al_4C_3 at the interface with diamond. This carbide is easily hydrolyzed so it may be disintegrated when exposed to coolant. Hence, aluminum typically is not a suitable carbide former to bond diamond in a matrix.

To avoid the high temperature of sintering, carbide formers, such as tungsten, are often diluted as minor constituents in the matrix that is made of primarily either Co or bronze. During the sintering process, there is a minimal amount, if any, of liquid phase formed. The diffusion of carbide former through a solid medium toward diamond is very slow. As a result, the formation of carbide on the surface of diamond is negligible. Therefore, by adding a carbide former as a minor matrix constituent, the improvement of diamond attachment is marginal at best.

In order to ensure the formation of carbide on the surface of diamond, the carbide former may be coated onto the diamond before mixing with the matrix powder. In this way, the carbide former, although it may be a minor ingredient in the matrix, can be concentrated around diamond to form the desired bonding.

The coating of diamond may be applied chemically or physically. In the former case, the coated metal is formed by a chemical reaction, generally at a relatively high temperature. For example, by mixing diamond with carbide formers

such as titanium or chromium, and heating the mixture under a vacuum or in a protective atmosphere, a thin layer of the carbide former may be deposited onto the diamond. Increasing temperature may increase the thickness of the coating. The addition of a suitable gas (e.g. HCl vapor) that assists the transport of the metal may also accelerate the deposition rate. Alternatively, the coating may be performed in a molten salt.

In addition to sintering, infiltration is also a common technique for making diamond tools; in particular for drill bits and other specialty diamond tools that contain large (i.e. greater than U.S. mesh 30/40) diamond grit. Most commonly used infiltrants for these tools are copper based alloys. These infiltrants must flow and penetrate the small pores in the matrix powder. In order to avoid the diamond degradation at high temperature, the melting point of the infiltrant must be low. Hence, the infiltrant often contains a low melting point constituent, such as zinc (Zn). In addition to lowering the melting point of the infiltrant, the low melting point constituent also reduces the viscosity so the infiltrant can flow with ease. However, as most carbide formers tend to increase the melting point of the infiltrant, they are excluded from most infiltrants. As a result, these infiltrants cannot improve the bonding of diamond.

One specific process that has become dependent on the use of diamond tools is chemical mechanical polishing (CMP). This process has become standard in the semi-conductor and computer industry for polishing wafers of ceramics, silicon, glass, quartz, etc. In general terms, the work piece to be polished is held against a spinning polishing pad of polyurethane, or other suitable material. The top of the pad holds a slurry of acid and abrasive particles, usually by a mechanism such as fibers, or small pores, which provide a friction force sufficient to prevent the particles from being thrown off of the pad due to the centrifugal force exerted by the pad's spinning motion. Therefore, it is important to keep the top of the pad as flexible as possible, and to keep the fibers as erect as possible, or to assure that there are an abundance of open and pores available to receive new abrasive particles.

A problem with maintaining the top of the pad is caused by an accumulation of polishing debris coming from the work piece, abrasive slurry, and polishing disk. This accumulation causes a "glazing" or hardening of the top of the pad, and significantly decreases the pad's overall polishing performance. Therefore, attempts

have been made to revive the top of the pad by "combing" or "cutting" it with various devices. This process has come to be known as "dressing" or "conditioning" the CMP pad. The device most widely used for pad dressing is a disk with a plurality of super hard crystalline particles, such as diamond particles or cBN particles attached thereto.

Dressing disks made by conventional methods share several problems with other superabrasive tools, made by conventional methods. However, such issues may have a much greater impact on the CMP process. For example, poor superabrasive grit retention may lead to scratching and ruining of the work piece. Uneven work loading of the superabrasive grits resulting from clustered or unevenly spaced particle groups may cause overdressing of certain pad areas and under dressing of others, which results in unsuitable work piece polishing. Moreover, when the superabrasive particles of dressing disks do not extend to a uniform height above the substrate surface of the disk uneven dressing of the CMP pad is further propagated, because many particles from the dresser may not touch the pad.

In addition to the above-recited issues with particle retention and distribution, the CMP pad dressing process itself creates additional issues that make uncontrolled superabrasive particle placement unacceptable. For example, the downward pressing force of a dressing disk on a CMP may depress the pad upon contact with the leading edge of the dresser, and prevent the remaining superabrasive particles on the pad dresser from sufficiently contacting the pad to achieve even dressing.

Warping of the pad dresser working surface during the brazing process also often causes abrasive particles to dislodge. During the brazing process the pad dresser must be exposed to very high temperatures. Exposure to this extreme heat can cause the working surface of the pad dresser to warp, thus compromising the smoothness and planarity of the pad dresser's working surface. As a result, the braze portion of the working surface will be rough, having high and low spots. Such spots are undesirable, as they may cause the braze to begin flaking off, and making micro-scratches on the polished surface of the work piece.

Another specific process that commonly utilizes tools constructed with superabrasive particles is the cutting of hard materials such as granite or steel. Such tools include circular saws, wire saws and frame saws. Although currently known

tools of each tool type has its advantages, each also has disadvantages that decrease its effectiveness in cutting hard materials.

The circular saw is typically a circular blade supported by a center shaft for rotation. Superabrasive particles are generally located around the periphery of the blade. These tools can rotate at a very high speed, in some cases up to 30 m/sec. This high speed of rotation translates into a high speed of cutting, making it economically advantageous. Even more advantageously, because of its circular nature the blade cuts in only one direction. During sawing, the metal matrix will gradually be chipped off to expose the diamond. Due to unidirectional cutting, the metal matrix will primarily be chipped off at the leading edge of the diamond, while the material behind the diamond will be shielded by the diamond itself. This uneven wear of the matrix material forms a "matrix trail" which helps to support the diamond from being pulled out of the saw by the repeated impact with the hard material, thus increasing the life of the saw blade.

At least two inherent properties of the circular saw limit its effectiveness as a tool to cut hard material. First, because the circular saw spins about a center of rotation, it is limited to a cutting depth of less than half of its diameter. Second, as the size of the circular saw is increased to increase the cutting depth, the distance between the cutting surface and the center of support increase. This results in a decrease in support at the periphery, causing the blade to wobble, and thus making it difficult to maintain a straight cutting path. This problem can be alleviated somewhat by increasing the thickness of the blade, but at the cost of increasing the kerf loss and thus reducing the useful material that can be cut from the source.

The wire saw is a continuous wire structure containing superabrasive coated segments. The wire saw cuts at high speeds using pulleys. It also cuts in one direction, thus creating matrix trails to support the diamond particles. The wire saw can also cut curvatures, and it is portable so it may be used on a job sight. One major disadvantage, however, stems from its flexible nature. Because of this, a straight cutting path is difficult to maintain.

The frame saw is essentially a straight blade supported at both ends that cuts in both directions. Because of the nature of the blade support and the vertical stiffness of the blade itself, frame saws make very straight cuts and have essentially no cutting depth restrictions. But several disadvantages inherent in the frame saw preclude its

use for cutting hard materials. Because the blade must overcome its forward momentum when reversing to cut in the opposite direction, the frame saw cannot attain the cutting speeds of the circular saw. Additionally, the bidirectional cutting action of the blade causes the metal matrix to be chipped away on both sides of the superabrasive particle, causing it to more readily pull out of the matrix and dramatically shortening the useful life of the blade.

Frame saw blades typically have superabrasive segments brazed along a cutting edge. The blades are manufactured with a slightly convex cutting edge so the blade more effectively presses against the diamond segments. Due to this force and the limited brazing area available along the cutting edge, the diamond segments are often knocked off the blade. Additionally, the blades are affixed into the frame saw under tension. This tension must be monitored and adjusted, and often results in broken blades.

Because of the limitations inherent to the frame saw, it has not been widely used to cut hard materials with superabrasive particles. In the cutting of granite, for example, a grinding technique is typically used. This is accomplished by sliding steel blades slowly back and forth against the rock while a slurry of iron grit in lime mud is fed into the cutting groove. The granite is gradually eroded away by chemical reaction and mechanical abrasion. This process is very slow, however, and it results in a slurry that is a pollutant that must be disposed of. Additionally, the cut surface is very rough and must be extensively polished. Finally, iron grits may be left embedded in the surface of the granite which may rust over time and cause staining.

As a result, suitable methods of maximizing the efficiency, useful life, and other performance characteristics of superabrasive and diamond tools are continually being sought.

SUMMARY OF THE INVENTION

Accordingly, in one aspect, the present invention provides a reciprocating frame saw blade for cutting a workpiece. Such a saw may include the components of a blade member having a concave cutting edge, and a plurality of superabrasive tool segments brazed along the cutting edge of the blade member. A variety of materials may be utilized for the blade member, the selection of which may be dictated in part by the type of workpiece to be cut, and the type of superabrasive tool segments to be

used. However, in one aspect, the blade member may be steel. In another aspect, the blade member may be flexible. A wide variety of mechanisms for producing a flexible blade can be utilized as is discussed in greater detail below. In some aspects, the concave configuration of the cutting edge may result from the blade member's flexibility.

In another aspect, the a saw blade for cutting a workpiece may include a blade member, and a plurality of superabrasive tool segments, each brazed to the blade member along a cutting edge and at least a portion of each side thereof. While as a general matter, the dimensions of the superabrasive tool segments will be substantially uniform, there may be times when it is desirable to have the sizes or dimensions differ. Such occurrences would be a matter of design choice selected by one of ordinary skill in the art, and may depend, at least in part, on various criteria, such as the type and of workpiece to be cut, and the proposed duration of the cutting activity. However, in one aspect, the superabrasive segments may be substantially uniform. In another aspect, they may be uniform in thickness. In yet another aspect, they may vary from one another. In a further aspect, they may be substantially equal to the width of the blade member.

The superabrasive tool segment that is to be used in saw embodiments, including both reciprocating and circular saws, of the present invention may take a variety of forms and have a variety of specific components as described herein. However, in one aspect, the tool segment may include a plurality of substrate layers arranged in a substantially parallel relationship, each layer having a plurality of superabrasive particles bonded thereto. In some aspects, the superabrasive particles may be chemically bonded with a brazing alloy, which in turn is bonded to the substrate. It has been found that, depending on the specific configuration and respective amounts of superabrasive particles and braze alloy, the superabrasive tool segment as recited above may be quite porous. Such porosity is desirable as it allows for the flow of a coolant through the segments which lowers the operating temperature of the tool during a material removal operation. The amount of porosity and size of the pores may be controlled by a variety of mechanisms, such as selection of the superabrasive particle pattern and concentration coupled with the amount of brazing alloy to be used. However, in one aspect, the superabrasive tool segment may

have a porosity of at least about 5%. In another aspect, the porosity may be at least about 10%.

By using a plurality of substantially parallel arranged substrates having superabrasive particles bonded therebetween, it has been found that the cutting efficiency of the superabrasive tool segment may be improved. Specifically, when made sufficiently thin, the plurality of substrate layers may allow an uncut ridge in a kerf to crumble to swarf. As a result a portion of the work material not directly contacted by a superabrasive particle is removed, and the overall efficiency of the tool is increased. In one aspect, the thickness of the substrate may be less than about 1mm. In another aspect, the thickness may be less than about 0.5 mm.

The present invention additionally encompasses methods for the fabrication and use of superabrasive tools, such as the present reciprocating saw blade and the associated superabrasive tool segments attached thereto. In one aspect, a method of making a superabrasive tool saw segment as recited in above may include the steps of: a) providing a plurality of substrate layers; b) arranging superabrasive particles on the substrate layers; c)assembling, or placing the substrate layers in a substantially parallel relationship; and d) chemically bonding the superabrasive particles to the substrate layers with a brazing alloy, such that the segment receives a porosity of at least about 5%.

There has thus been outlined, rather broadly, various features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying claims, or may be learned by the practice of the invention.

Additional features and advantages of the invention will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a final tool segment produced in accordance with an embodiment of the present invention;

FIG. 2 is a side view of a segment showing placement of superabrasive particles using a template;

FIG. 3 is a side view of a segment showing a method of placing superabrasive particles on a substrate using a transfer plate;

FIG. 4 is a side view of a segment showing an alternative method of forming a pattern of superabrasive particles;

FIG. 5 is a side view of a precursor segment showing a possible placement of the braze alloy;

FIG. 6A shows a segment from a super abrasive tool fomed by a plurality of linear, longitudinal layers disposed adjacent one another to form a three-dimensional super abrasive member;

FIG. 6B shows a cross-sectional view of one typical configuration of the tool segment shown in FIG. 6A, wherein a layer formed by a matrix support material and a relatively large superabrasive is sandwiched between two layers of matrix support materials, which have smaller grit, and higher concentration of the abrasive;

FIG. 7A shows a segment from a superabrasive tool formed by a plurality of arcuate, longitudinal layers, which are attached to one another to form a three-dimensional super abrasive member;

FIG. 7B shows a cross-sectional view of a plurality of layers matrix support material as may be used with the segment shown in FIG. 7A;

FIG. 8 shows another possible layout of a segment of a cutting tool with transverse layers configured with a denser concentration of abrasive material disposed at a forward, cutting end of the three-dimensional super abrasive member;

FIG. 9 shows yet another layout of a segment wherein a three-dimensional super abrasive member is formed with progressively denser abrasive distribution toward the upper surface of a tool with horizontal layers;

FIGS. 10A through 10D show one possible method for forming layers with controlled superabrasive distribution within the layer;

FIGS. 11A through 11C show an alternate method for forming one or more layers with controlled superabrasive distribution;

FIGS. 12A through 12C show another alternative method for forming one or more layers with controlled superabrasive distribution using a sheet of amorphous brazing alloy.

FIG. 13 shows a side view of a consolidated tool segment formed from multiple layers having a three-dimensional pattern of superabrasives;

FIG. 14 shows a perspective view of a frame saw blade as known in the prior art;

FIG. 15 shows a perspective view of a frame saw blade in accordance with an embodiment of the present invention;

FIG. 16 shows a perspective view of a superabrasive segment in accordance with an embodiment of the present invention;

FIG. 17 shows a cross sectional view of the attachment of a superabrasive segment to the blade member in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Alterations and further modifications of the inventive features, process steps, and materials illustrated herein, and additional applications of the principles of the inventions as illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the invention. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

A. Definitions

In describing and claiming the present invention, the following terminology will be used.

The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a matrix material" includes reference to one or more of such materials, and reference to "an alloy" includes reference to one or more of such alloys.

As used herein, "substantially free of" refers to the lack of an identified element or agent in a composition. Particularly, elements that are identified as being "substantially free of" are either completely absent from the composition, or are

included only in amounts which are small enough so as to have no measurable effect on the composition.

As used herein, "predetermined pattern" refers to a non-random pattern that is identified prior to construction of a tool, and which individually places or locates each superabrasive particle in a defined relationship with the other diamond particles, and with the configuration of the tool. For example, "positively planting particles in a predetermined pattern" would refer to positioning individual particles at specific non-random and pre-selected positions. Further, such patterns are not limited to uniform grid patterns but may include any number of configurations based on the intended application.

As used herein, "amorphous braze" refers to a homogenous braze composition having a non-crystalline structure. Such alloys contain substantially no eutectic phases that melt incongruently when heated. Although precise alloy composition is difficult to ensure, the amorphous brazing alloy as used herein should exhibit a substantially congruent melting behavior over a narrow temperature range.

As used herein, "uniform grid pattern" refers to a pattern of diamond particles that are evenly spaced from one another in all directions.

As used herein, "irregularly shaped" refers to a shape that is not a standard geometric shape, e.g. shapes that are not round, oval, square, etc.

As used herein, "matrix," "matrix support material," "matrix support layer," and "matrix material," may be used interchangeably, and refer to a non-sintered particulate material to which superabrasive particles may be bonded. Notably, sintering or consolidation of the particulate material may occur during a process of chemically bonding superabrasive particles thereto. In one aspect, the superabrasive particles may be bonded or fixed to a surface of the matrix. In another aspect, the superabrasive particles may be fixed or planted into the matrix. In yet another aspect, the matrix material may take the shape of a tool body. In a further aspect, the matrix material may take the shape of a sheet having a specified thickness.

As used herein, "substrate" refers to a solid metal material. While many solid metal materials may be a product of metal particulate sintering or consolidation, it is to be understood, that as used herein, "substrate" does not include powdered or particulate metal materials that have not yet been sintered or consolidated into a solid mass or form.

As used herein, "alloy" refers to a solid or liquid mixture of a metal with a second material, said second material may be a non-metal, such as carbon, a metal, or an alloy which enhances or improves the properties of the metal.

As used herein, "metal brazing alloy," "brazing alloy," "braze alloy," "braze material," and "braze," may be used interchangeably, and refer to a metal alloy which is capable of chemically bonding to superabrasive particles, and to a matrix support material, or substrate, so as to substantially bind the two together. The particular braze alloy components and compositions disclosed herein are not limited to the particular embodiment disclosed in conjunction therewith, but may be used in any of the embodiments of the present invention disclosed herein.

As used herein, the process of "brazing" is intended to refer to the creation of chemical bonds between the carbon atoms of the superabrasive particles and the braze material. Further, "chemical bond" means a covalent bond, such as a carbide or boride bond, rather than mechanical or weaker inter-atom attractive forces. Thus, when "brazing" is used in connection with superabrasive particles a true chemical bond is being formed. However, when "brazing" is used in connection with metal to metal bonding the term is used in the more traditional sense of a metallurgical bond or a mechanical bond such as is present in welding or soldering Therefore, brazing of a superabrasive segment to a tool body does not require the presence of a carbide former.

As used herein, "superabrasive particles" and "superabrasive grits" may be used interchangeably, and refer to particles of either natural or synthetic diamond, super hard crystalline, or polycrystalline substance, or mixture of substances and include but are not limited to diamond, polycrystalline diamond (PCD), cubic boron nitride (CBN), and polycrystalline cubic boron nitride (PCBN). Further, the terms "abrasive particle," "grit," "diamond," "PCD," "CBN," and "PCBN," may be used interchangeably.

As used herein, in conjunction with the brazing process, "directly" is intended to identify the formation of a chemical bond between the superabrasive particles and the identified material using a single brazing metal or alloy as the bonding medium.

As used herein, "precursor" refers to an assembly of superabrasive particles, substrate or matrix support material, and/or a braze alloy. A precursor describes such an assembly prior to the brazing and/or sintering process, i.e. such as a "green body".

As used herein, "aperture" refers to an opening through a template surface which has a predetermined size and shape depending on the intended application. For example, the aperture size may be designed to accommodate a plurality of superabrasive particles of a given mesh size. However, it is often desirable to design the apertures such that only one superabrasive particle is accommodated by each aperture.

As used herein, "euhedral" means idiomorphic, or having an unaltered natural shape containing natural crystallographic faces.

As used herein, "sharp portion" means any narrow apex to which a crystal may come, including but not limited to corners, ridges, edges, obelisks, and other protrusions.

As used herein, "metallic" means any type of metal, metal alloy, or mixture thereof, and specifically includes but is not limited to steel, iron, and stainless steel.

As used herein with respect to distances and sizes, "uniform" refers to dimensions that differ by less than about 75 total micrometers.

Concentrations, amounts, and other numerical data may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited.

For example, a concentration range of about 1% w/w to about 4.5% w/w should be interpreted to include not only the explicitly recited concentration limits of 1% w/w to about 4.5% w/w, but also to include individual concentrations such as 2% w/w, 3% w/w, 4% w/w, and sub-ranges such as 1% w/w to 3% w/w, 2% w/w to 4%w/w, etc. The same principle applies to ranges reciting only one numerical value, such as "less than about 4.5% w/w," which should be interpreted to include all of the above-recited values and ranges. Further, such an interpretation should apply regardless of the breadth of the range or the characteristic being described.

B. The Invention

Reference will now be made to the drawings in which the various elements of the present invention will be given numeral designations and in which the invention will be discussed. It is to be understood that the following description is only

exemplary of the principles of the present invention, and should not be viewed as narrowing the appended claims.

Referring to FIG. 14 there is shown a perspective view of a frame saw200 as is known in the prior art. The saw generally comprises a steel blade 202 having diamond segments 204 silver brazed to the cutting edge. The blade 202 is typically manufactured with a slightly convex cutting edge to more effectively push against the diamond segments 204. The frame saw 200 is shown sitting in the cutting groove or kerf 206 of a section of rock 208. The arrows 210 represent the back and forth motion of the blade 202 when cutting the rock 208, demonstrating that essentially all of the force exerted to move the blade 202 is in the horizontal direction with little or no downward component. Therefore any downward force to cut the rock must be introduced directly by the operator or the machine holding the blade 202.

FIG. 15 shows a perspective view of one possible embodiment of a frame saw blade 220 according to the present invention. The frame saw blade 220 comprises a blade member 222 having superabrasive tool segments 224 brazed thereto. The superabrasive tool segments may vary in dimension as required for a particular cutting application, and may further vary in dimension from one another. In one aspect, the segments may be substantially uniform in width. In another aspect, the segments may be non-uniform in width. In yet another aspect, the segments may have a width that is substantially equal to the width of the blade member.

The frame saw blade 220 is shown sitting in the kerf 226 of a workpiece 228, where the blade member 222 cuts with a concave cutting edge 230. The arrows 232 represent the force applied to the frame saw blade 220 to move it back and forth across the workpiece. The concave shape of the blade member 222 generates a downward force 234 towards the workpiece as the frame saw blade 220 is drawn back and forth. Unlike the wire saw, the frame saw blade 220 is stiff along its vertical axis, allowing it to cut a straight kerf.

The blade member 222 may be constructed as a concave member, or it may conform to a concave shape during a cutting operation due to flexibility of the blade member 222. This flexibility may be a result of the blade member 222 being constructed as a chain saw, a hinged saw, or any segmented saw, or other method of attaining a limited flexibility known to one skilled in the art. It is important, however, that the blade member 222 be stiff enough along its vertical axis to maintain a straight

cutting groove. It is preferred that the blade member 222 be constructed of steel, however it is contemplated that other suitable materials may be used.

Referring now to FIG. 1, a plurality of superabrasive particles 20 are brazed to an exposed surface of substrate 102 in accordance with a predetermined pattern. A braze material 25 is used to braze or bond the superabrasive particles to the substrate. In keeping with the present invention, a variety of methods may be used to obtain the desired results and are discussed in more detail below.

The substrate may include a variety of materials, such as various metals. Examples of specific metals include without limitation, cobalt, nickel, iron, copper, carbon, and their alloys or mixtures (e.g. tungsten or its carbide, steel, stainless steel, bronze, etc). The present invention is useful for a variety of diamond tools such as for grinding, polishing, cutting, dressing or any tool used to remove material from a workpiece. For example, saws are not limited to, but may include, circular saws, straight blades, gang saws, reciprocating saws, frame saws, wire saws, thin-walled cutoff saws, dicing wheels, and chain saws. In another aspect, the diamond tool may be a CMP pad conditioner.

Typically, the substrate has an exposed surface upon which the superabrasive particles are to be affixed and may be substantially flat or contoured and may have multiple faces, such as in some drill bits or circular saws. However, in one embodiment of the present invention, the superabrasives may be bonded to a matrix support material rather than directly to a substrate. The matrix support material may either be sufficiently configured to act as a tool body, or may be further coupled to a substrate to form a complete tool.

In another alternative embodiment, the abrasive particles may be temporarily affixed to a substrate with an acrylic glue, or other adhesive using the template as described below in order to prevent movement during the brazing process. Most common adhesives will vaporize at temperatures above about 400° C and do not chemically react with the braze alloy or superabrasive particles.

The brazing alloy of the present invention may be provided as a thin sheet, powder, or continuous sheet of amorphous braze alloy. Additionally, the brazing alloy may be provided as a solidified molten alloy that is coated on the superabrasive particles. Such a coating may occur individually or collectively with respect to the superabrasive particles. There are various ways such a brazing alloy can be

incorporated into a superabrasive tool in accordance with the present invention. For example, a brazing alloy powder can first be mixed with a suitable binder (typically organic) and a solvent that can dissolve the binder. This mixture is then blended to form a slurry or dough with a proper viscosity. In order to prevent the powder from agglomeration during the processing, a suitable wetting agent (e.g., menhaden oil, phosphate ester) may also be added. The slurry may then be sprayed or otherwise applied to the matrix support material and/or superabrasive particles. In another embodiment, the slurry can then be poured onto a plastic tape and pulled underneath a blade or leveling device. By adjusting the gap between the blade and the tape, the slurry can be cast into a plate with the desired thickness. The tape casting method is a well-known method for making thin sheets out of powdered materials and works well with the method of the present invention.

The brazing alloy may also be provided as a sheet of amorphous brazing alloy. The sheet of amorphous brazing alloy may be flexible or rigid and may be shaped based on the desired tool contours. This sheet of brazing alloy also aids in the even distribution of the braze over the surface of the tool. The sheet of brazing alloy contains no powder or binder, but rather is simply a homogenous braze composition. Amorphous brazing alloys have been found to be advantageous for use in the present invention, as they contain substantially no eutectic phases that melt incongruently when heated. Although precise alloy composition is difficult to ensure, the amorphous brazing alloy used in the present invention should exhibit a substantially congruent melting behavior over a relatively narrow temperature range. Thus, during the heating portion of the brazing process the alloy does not form grains or a crystalline phase in substantial quantities, i.e. via vitrefication. Further, the melting behavior of the amorphous braze alloy is distinct from sintering which requires the reduction or elimination of voids between particles of alloy material which does not exist in the amorphous form of the alloy. However, the originally amorphous braze may form non-homogeneous phases during crystallization via the slower cooling process. Generally, amorphous alloys are formed by quickly quenching the liquid into a solid to avoid localized crystallization and variations in composition. Notably, in each of the processes recited herein, the brazing alloy may be presented as either a sheet, film, or other punched out layer that corresponds to the desired tool segment shape.

Alternatively, a powdered brazing alloy can be mixed with a suitable binder and its solvent to form a deformable cake. The cake can then be extruded through a die with a slit opening. The gap in the opening determines the thickness of the extruded plate. Alternatively, the material can also be drawn between two rollers with adjustable gap to form sheets with the right thickness. In another aspect, the braze powder may be showered directly onto diamond particles and substrate as more fully elaborated below.

It is desirable to make the sheets pliable for subsequent treatments (e.g., bending over the tool substrate). Therefore, a suitable organic plasticizer can also be added to provide the desired characteristics.

The use of organic agents for powder (metal, plastics, or ceramics) processing is documented in many textbooks and it is well known by those skilled in the art. Typical binders include polyvinyl alcohol (PVA), polyvinyl butyral (PVB), polyethylene glycol (PEG), paraffin, phenolic resin, wax emulsions, and acrylic resins. Typical binder solvents include methanol, ethanol, acetone, trichlorethylene, toluene, etc. Typical plasticizers are polyethylene glycol, diethyl oxalate, triethylene glycol dihydroabietate, glycerin, octyl phthalate. The organic agents so introduced are to facilitate the fabrication of metal layers. They must be removed before the consolidation of metal powders. The binder removal process (e.g., by heating in a furnace with atmospheric control) is also well known to those skilled in the art.

In one aspect, the brazing alloy may be substantially free of zinc, lead, and tin. One commercially available powdered braze alloy, which is suitable for use with the present invention, is known by the trade name NICROBRAZ LM (7 wt% chromium, 3.1 wt% boron, 4.5 wt% silicon, 3.0 wt% iron, a maximum of 0.06 wt% carbon, and the balance comprising nickel), made by Wall Colmonoy Company, Madison Heights, Michigan. Other suitable alloys included copper, aluminum, and nickel alloys containing chromium, manganese, titanium, and silicon. In one aspect, the brazing alloy may include chromium. In another aspect, the brazing alloy may include a mixture of copper and manganese. In an additional aspect, the amount of chromium, manganese, and silicon may be at least about 5 percent by weight. In another aspect, the alloy may include a mixture of copper and silicon. In yet another aspect, the alloy may include a mixture of aluminum and silicon. In a further aspect,

the alloy may include a mixture of nickel and silicon. In another aspect, the alloy may include a mixture of copper and titanium.

Preferably, the diamond braze contains at least 3% by weight of a carbide forming member selected from the group consisting of chromium, manganese, silicon, titanium, and aluminum, and alloys and mixtures thereof. Additionally, the diamond braze should have a liquidus temperature of less than 1,100° C to avoid damage to the diamond during the brazing process. One commercially available sheet ofamorphous brazing alloy which melts at a sufficiently low temperature is an amorphous brazing alloy foil (MBF) manufactured by Honeywell having the NICROBRAZ LM composition. These foil sheets are about 0.001" thickness and typically melt at between about 1,010° C and about 1,013° C.

In one aspect, the brazing process may be carried out in a controlled atmosphere, such as under a vacuum, typically about 10^{-5} torr, an inert atmosphere (e.g., argon (Ar) or nitrogen (N_2)), or a reducing atmosphere (e.g., hydrogen (H_2)). Such atmospheres may increase the infiltration of the brazing alloy into the matrix support material, and therefore, enhance the diamond-braze and matrix-braze bonding.

Referring now to FIG. 2, a substrate 102 is selected and a template 110is laid on the top of the substrate. The template 110 contains apertures 114 that are larger than one superabrasive particle, but smaller than two abrasive particles, thereby allowing a single particle of the abrasive to be disposed at each specific locaton. The thickness of the template is preferably between 1/3 to 2/3 of the height of the average abrasive particle. However, other thicknesses may be used if appropriate accommodations are made for seating the abrasive particles in the desired locations. In some aspects, the thickness of the template may be up to two (2) times the height of the abrasive particles. An adhesive may be applied to the surface of the substrate to hold the superabrasive particles in place during the brazing process.

After the template 110 is properly positioned, a layer of abrasive particles 20 is then spread over the template so that each aperture 114 receives an abrasive particle. Those particles not falling into the apertures in the template are removed by tilting the substrate, sweeping the template with a broom, or some other similar method. Optionally, a generally flat surface, such as a steel plate, may then be laid over the superabrasive particles, which rest in the apertures in the template. The flat

surface presses the superabrasive particles to seat the particles. The pressed particles are therefore firmly attached to the substrate by either slight mechanical impression into the substrate, or into a braze layer (not shown), or adhesive layer (not shown) which was applied to the exposed surface of the substrate prior to placing the superabrasive particles thereon. The template 110 is then removed such that the superabrasive particles 20 remain in place on the substrate 102 in accordance with the predetermined pattern of the template.

Alternatively, as shown in FIG. 3, the substrate may be a transfer plate 106 onto which the superabrasive particles 20 are affixed to one side using a thin adhesive film (not shown). Optionally, the same methods as described above with regard to using a template 110 to achieve a particular pattern of superabrasive particles may be used to effect particle placement. The transfer plate 106 having superabrasive particles 20 affixed thereon is then pressed against a substrate 102. The trasfer plate may be made of metal or plastic, however it has been found that a transparent plastic transfer plate increases ease of use and facilitates monitoring of the process. Affixing of the particles to the transfer plate may be accomplished using any adhering means, such as an adhesive. In order to facilitate transfer of the superabrasive particles to the substrate 102 an adhesive layer (not shown) which adheres the particles 20 more strongly to the substrate 102 than to the transfer plate can be used. The transfer plate is then removed and treatment such as adding a braze to form a tool precursor and heating to produce the final product may be performed. Therefore, the abrasive particles are transferred to the substrate in the pattern dictated by the template.

In another alternative embodiment, the transfer sheet 106 may be a sheet of amorphous brazing alloy. In a similar process to that described above, the superabrasive particles 20 are affixed to a substrate. First, a template 110 having apertures 114 is placed upon a sheet of brazing alloy 106, as illustrated in FIG. 4. In one aspect of the present invention, the sheet may be a sheet or film of continuous amorphous brazing alloy, as described above. The use of the template allows controlled placement of each abrasive particle at a specific location by designing the template with apertures in a desired pattern.

After the template 110 is place on the brazing alloy sheet, the apertures 114 are filled with abrasive particles 20. The apertures have a predetermined size, so that only one abrasive particle will fit in each. Any size of abrasive particle, or grit is

acceptable, however in one aspect of the invention, the particle sizes may be from about 100 to about 350 micrometers in diameter. Although various aperture sizes and shapes would restrict access to one particle per aperture, the apertures of the present invention may be designed for very careful placement of the superabrasive particles. Thus, for average particle sizes of 100 micrometers the apertures could be designed about 150 micrometers across.

In another aspect of the invention, the size of the apertures in the template may be customized in order to obtain a pattern of abrasive particles having a size within a uniform size range. In one particular embodiment of CMP pad dressing, the apertures of the template are sufficient to select only grits within a size range having a variance no greater than 50 micrometers. This uniformity of grit size contributes to the uniformity of CMP pad dressing, as the workload of each abrasive particle is evenly distributed. In turn, the even workload distribution reduces the stress on individual abrasive particles, and extends the effective life of the CMP pad dresser. In various superabrasive tools, the template may take a wide variety of configurations. The patterns may include various arrangements, as well as, include multiple size apertures to accommodate differing size superabrasive particles in the same tool in which case the larger particles would be applied first followed by the smaller particles.

After the apertures of the template are all filled with superabrasive particles, any excess abrasive particles are removed, and optionally a flat surface is applied to the abrasive particles. The flat surface should be of an extremely strong, rigid material, so that it is capable of pushing abrasive particles down into the brazing alloy sheet or film 106. Such materials typically include, but are not limited to steel, iron, alloys thereof, etc.

After removing the template, the flat surface may be used again to press the abrasive particles firmly into the sheet of brazing alloy. While a flat surface is preferable, those skilled in the art will appreciate that there may be occasions when it is desirable to have some of the abrasive particles extend outwardly from the final tool more than other abrasive particles. In such situations, a contoured or otherwise shaped surface could be used to seat some of the abrasive particles deeper into the sheet of brazing alloy, than other particles. The abrasive particles will thus extend away from the substrate to a predetermined height.

While the method described above to press the superabrasive particles into the brazing alloy is preferred for many applications, there are instances where it is desirable to have the abrasive particles extend outwardly from the sheet of brazing alloy. For example, some tools may only have one layer of abrasive. This can be accomplished simply by leaving the template 110 in place when pressing the superabrasives using a flat surface, and not further pressing the particles into the brazing alloy once the template has been removed.

In the alternative, the sheet or film of brazing alloy in FIGS. 3 through 5 is formed to be of a lesser thickness than the cross-sectional thickness or diameter of the superabrasive particles 20. When the particles are pressed into the sheet 106, the thickness of the sheet forces the particles to protrude from the sheet of brazing alloy. The sheet is then applied to the matrix support material in a manner discussed above.

In creating the predetermined pattern of the present invention, the spacing of the apertures in the template, while non-random, need not be uniform. Rather, variations in spacing can be provided to facilitate different concentrations on various areas to facilitate different concentrations on various portions of the sheet of amorphous brazing alloy. Likewise, by controlling the size of the apertures and the order in which the diamond particles are placed in the apertures, a single layer could be provided with particles of different sizes.

In a more detailed aspect of the present invention, superabrasive particle height may be important in CMP pad dresser performance. A uniform particle height can be determined by the thickness of the template 110, and in a preferred embodiment, each abrasive particle will extend to within 50 micrometers of this distance. As such, each abrasive particle grooms to substantially the same depth on the CMP pad. However, it is to be understood that in certain applications, grit height may not be desired to be uniform. As such, those of ordinary skill in the art will recognize that grit patterns of varied height may be provided by so configuring the template, and the surface used to press the particles to provide such a design.

Abrasive particles 20 as shown in FIGS. 1-12C are various shapes. The scope of the present invention encompasses abrasive particles of any shape, including euhedral, or naturally shaped particles. However, in one embodiment, the abrasive particles have a predetermined shape with a sharp point extending in a direction away from the substrate.

In an alternative embodiment, rather than pressing the abrasive particles into the sheet of brazing alloy, they may be fixed in the templated position by disposing an adhesive on the surface of the sheet of brazing alloy. In this manner, the particles remain fixed in place when the template is removed, and during heat processing.

While the use of the sheet of amorphous brazing alloy 106 been discussed with respect to the patterned distribution of superabrasive particles, it is equally applicable to the random distribution of diamond particles on a matrix support material. Thus, the superabrasive particles may be distributed on either the sheet of brazing alloy or a matrix support material without the use of a template or otherwise creating a predetermined pattern. Similar methods and arrangements could be employed as described above in connection with the use of a template.

After the superabrasive particles are at least partially embedded in, or adhered to, the sheet of brazing alloy 106, the sheet is affixed to the substrate 102 as shown in FIG. 5. Alternatively, in some embodiments, the sheet of brazing alloy may be first affixed to the substrate, and the abrasive particles subsequently added thereto using the template procedure described herein. In another alternative embodiment, the sheet of brazing alloy having superabrasive particles affixed thereto is applied to the exposed surface of the substrate in such a manner that the superabrasive particles are oriented between the sheet and the substrate as shown in FIG. 3.

The brazing alloy used in several embodiments of the present invention may be any brazing material known in the art, but in one aspect, may be a nickel alloy that has a chromium content of at least about 2% by weight. A brazing alloy of such a composition will be nearly super hard in and of itself, and less susceptble to chemical attack from solutions used in various applications such as an abrasive containing slurry. In such an embodiment, additional anti-corrosive layers or overlay material would be optional.

Because the abrasive particles are firmly held in, or on the sheet of brazing alloy, the surface tension of the liquid brazing alloy is insufficient to cause particle clustering during the brazing process. Additionally, braze thickening occurs to a much lesser degree and few or no "mounds" are formed. Rather, the braze 25 forms a slightly concave surface between each abrasive particle, due to the wetting action of the chemical bonding between the braze and the particles, which provides additional structural support, as shown in FIG. 1. In one embodiment, the thickness of the sheet

of amorphous brazing alloy 106 is predetermined to allow at least about 10% to about 90% of each abrasive particle to protrude above the outer, or working, surface of brazing material. In another aspect, when an overlay material is used, the abrasive particles may be selected or placed, so that at least about 10% to about 90% of each abrasive particle protrudes above the outer, or working, surface of the overlay material.

In addition to the specific methods of embedding, or adhering the abrasive particles to the sheet of brazing alloy, those skilled in the art will recognize suitable alternative procedures, such as fixing the abrasive particles to the substrate, and then placing the braze thereon. In this case, the particles may be positioned on the substrate using the template method recited above, and held in place by glue, or other suitable binder. Alternatively, a powdered braze material is then showered, or placed on the substrate around the abrasive particles and heated to cause the braze material to form chemical bonds with the superabrasive particles and bond to the substrate.

Once the superabrasive particles and brazing alloy have been placed on the substrate, or matrix support material, to form a superabrasive tool precursor the precursor is heated to braze the superabrasives to the matrix support material. The selection of the brazing alloy is important and directly affects the final tool properties such as durability and strength. Although many types of brazing alloys are commercially available, the brazing alloys useful in connection with the present invention are limited. The brazing alloy should contain a carbide former as discussed above, such as titanium, vanadium, chromium, zirconium, molybdenum, tungsten, manganese, iron, silicon, aluminum, and mixtures or alloy thereof.

Of particular importance are chromium, manganese, silicon or alloys or mixtures thereof and have proven effective in the present invention. The carbide former may be present in the brazing alloy between about 2% and about 50% by weight of the brazing alloy. Examples of these brazes are NICROBRAZ LM (Ni-Cr-B-Si-Fe), manufactured by Wall Colmonoy Company (U.S.A.), with a melting range of 970-1000° C, and 21/80 (Cu-Mn-Ni), manufactured by Degussa (Germany), with a melting range of 970-990° C. Other possible brazes include: Cu-Mn alloy near the eutectic composition (about 25 wt% Mn) with a melting point of about 880° C; Ni-Si alloy near the eutectic composition (about 50 wt% Si) with a melting point of about 970° C; Cu-Si alloy near the eutectic composition (about 30 wt% Si) with a melting

point of about 810° C; Al-Si alloy near the eutectic composition (about 15 wt% Si) with a melting point of about 600° C.

The above-recited examples of diamond brazes cover a wide range of mechanical properties and infiltration or sintering temperatures (generally about 50° C above the liquidus temperature). Various alloys of these brazes may also be used for further adjustments of brazing temperature and mechanical properties. The selection of diamond braze depends largely on the intended application. In general, more severe applications, such as sawing granite, concrete, or asphalt, would require a stronger diamond grit that may tolerate a higher temperature of brazing. Brazes which melt at higher temperatures are, in general, more wear resistant. On the other hand, less demanding applications, such as sawing limestone or marble, require lower strength diamond grit. Such a diamond is degraded easily at high temperature so it must be brazed at a lower temperature. Brazes of this type are typically less wear resistant.

Brazing material should be kept to a minimum in order to avoid completely covering the abrasive particles. This problem is compounded by the fact that typical brazing materials are mechanically very weak. This mechanical weakness offsets the strength of the chemical bonds created between the abrasive particles and the brazing material. In fact, when dislodgment occurs, the chemical bonds between the abrasive particles and the brazing material are strong enough that the brazing material itself will often shear off along with detached abrasive particles. The brazing material is also very susceptible to chemical attack by the abrasive slurry. This contributes to the detachment of abrasive particles, as it further weakens the brazing material, which is already mechanically weak.

While prior art brazes typically include metals which were designed to facilitate flow of the braze material, such as zinc, lead and tin, it has been found in accordance with the present invention that such materials actually impair the brazing process. The prior art materials are generally more volatile, and have a tendency to contaminate the vacuum or inert atmosphere used in infiltration. While very small amounts of the volatile metals will not significantly interfere with brazing, amounts over about 1 or 2 percent by weight can inhibit proper infiltration. As used herein, substantially free of volatile metals, or substantially free of zinc, etc. is used to

characterize such a situation in which the volatile metal is present in sufficiently small amounts as to not provide any meaningful impediment to infiltration and brazing.

It is important that the brazing temperature be kept lower than the melting point of the substrate so the tool body can maintain the shape during the brazing of the superabrasive particles. Moreover, the brazing temperature must also be low enough to not cause diamond to degrade, typically less than about 1,100° C. For embodiments involving infiltration, a temperature typically 50° C above the liquidus temperature of the braze alloy is required. In addition to control the brazing temperature, the brazing time should also be kept short so the braze will not react excessively with diamond or the substrate. In the former case, diamond may also be degraded. In the later case, the alloying with the surface of the substrate may raise the melting point of the diamond braze. As a result, the diamond braze may solidify gradually and eventually stop flowing. Also, a coarse braze powder will require longer heating times and/or temperatures.

An additional consideration in selection of a brazing alloy is that it should also wet the superabrasive particles and chemically bond with the superabrasives. Therefore, as the brazing alloy 25 bonds with the superabrasive particles the alloy creeps up the sides of the superabrasives as can be seen in FIG. 1. This wetting action is beneficial for several reasons including improved mechanical support for the particles, as well as the strong carbide bonds. Typically, a carbide former contained in a suitable solvent alloy meets this requirement. However, various carbide formers may be adversely impacted by the brazing atmosphere.

The atmospheric environment for brazing also may be controlled to provide superior performance. For example, if the braze material contains a strong attractor of oxygen or nitrogen, such as titanium, a high degree of vacuum (10^{6} torr maximum), or a dew point below -60° C, must be maintained during the brazing process. This restraint often adds unnecessary costs to manufacturing of diamond bond tools. The presence of minute amounts of oxygen may oxidize the carbide former and prevent the formation of carbide bonds with the diamond. On the other hand, if the braze material contains a less sensitive getter, such as chromium and manganese, a lower degree of vacuum (10^{-5} torr minimum) or a hydrogen atmosphere may be adequate for brazing. However, if the carbide former reactivity is too low, such as with cobalt or nickel, minimal carbide bonds will be formed with the diamond particles. Hence

there is a compromise in selection of carbide formers between the ability to bond with diamond and the tendency to oxidize.

After brazing, the produced part (e.g., a saw segment) may be trimmed (e.g., by grinding) to the finished dimension. It can then be mounted (e.g., by conventional brazing) onto a tool body (e.g., a round steel blade) to make a finished product.

As discussed above, this invention uses a diamond braze that wets the matrix support material of a diamond tool. Most diamond brazes can wet easily common matrix support materials with major constituents of cobalt, nickel, iron, copper or bronze, so the brazing may proceed smoothly. Referring again to FIG. 1, typically, the final diamond tool produced in accordance with the method of the present invention includes diamond particles 20 having carbide bonds with a component of the braze alloy, such as chromium, and a braze 25 containing various eutectic phases which includes both mechanical brazing and partial alloying with the substrate 102.

In addition to brazing using the methods described above, the bonding of the diamond particles to the matrix material using the brazing alloy may be accomplished by mixing a powdered form of brazing alloy with a powdered form of matrix material. The organic binder is then added, and the matrix support material and brazing alloy are formed into a sheet, or layer as described above. Diamond particles are then distributed by being positioned or located in a predetermined pattern using a template as described. The sheet may then be stamped, or pressed into desired tool shapes, which are heated to a temperature sufficient to bond the diamond particles to the matrix support material using the brazing alloy, as well as to sinter together the metal particles of the matrix. Such a process generally may be accomplished using low temperatures which do not incur many of the afore-warned risks to the tool.

The most widely used matrix powder for making diamond tools (e.g., saw segments) is cobalt powder. The standard sizes of cobalt powder for making conventional diamond tools are less than 2 micrometers. In the last decade, the diamond tool manufacturers have demanded finer and finer matrix powders. The commercial suppliers (e.g., Eurotungsten Co.) are therefore, moving toward making ultrafine (one micrometer), and even ultra-ultrafine (submicron) powders. With such a trend, the sintering temperature is continuously decreasing. A lower sintering temperature not only reduces the degradation of diamond; it also reduces the cost of

manufacturing. For example, the powder consumption is lower. Moreover, the oxidation loss of graphite mold is also minimized.

However, one embodiment of the present invention uses a diamond braze to fill up the pores of the matrix powder. Hence, coarse-sized powders, i.e. greater than 400 U.S. mesh or 34 microns, are preferred. Moreover, while conventional methods require the density be as high as possible so sintering can proceed rapidly, it is preferred in the present invention to use a precursor with a lower packing density to allow the easy flow of the diamond braze. In fact, sometimes, the porosity of the precursor body may be intentionally increased by using irregularly shaped matrix particles. This preference, again, is contrary to the conventional wisdom that requires the particles be as spherical as possible so the packing density can beincreased.

The use of a coarse matrix powder has other benefits. For example, a coarse powder can mix better with different compositions. Hence, the diamond grit may distribute more uniformly in the matrix. Moreover, a coarse powder has a smaller surface area, and hence, a lower frictional force for infiltration. Therefore, it can flow easier in the mold. Of course, a coarse matrix powder is also much less expensive, so the production cost may be reduced.

It is important to note that this invention utilizes the matrix merely as the network for holding the diamond grit in place. Hence, the matrix may not have to be made of powder. For example, the matrix body may be made of a piece of steel with openings that contain diamond grits of PCD bodies. Further, the superabrasive containing segments may be easily formed to accommodate a variety of substrate shapes prior to brazing.

In another alternative embodiment of the present invention, a three-dimensional tool is formed having a predetermined pattern of diamond grits therein. By assembling substantially two-dimensional segments to form a three-dimensional body, the distribution of diamond grit in a tool can be positively controlled. Thus, diamond concentration in different parts of the same tool may be adjusted (see FIGS. 6A through 9). Such a control of diamond distribution is highly desirable to improve the wear characteristics of the tool. For example, the sides of a diamond saw blade are often worn faster then the center, so it is advantageous to add more diamond grit on the sides (see FIG. 6B).

Referring to FIG. 6A, there is shown a perspective view of a tool segment, generally indicated at 10, formed by a plurality of layers, 14, 16 and 18. Each of the layers 14, 16 and 18 is formed by matrix support material impregnated with diamond particles, indicated by the dark circles 20, and has been infiltrated with a braze selected to chemically bond to the diamond particles and the matrix support material, such bonding firmly holds the particles in the matrix support material. Preferably, the diamond particles 20 constitute less than 50 percent of the matrix support material-diamond mixture, and more preferably less than 40 percent. Keeping the amount of diamond particles to the minimum helps to minimize cost while optimizing the useful life of the product. Although FIGS. 6A through 9 show discrete layers of matrix support material, the final sintered tool segment is essentially a continuous metal matrix having superabrasive particles distributed in a particular three-dimensional pattern. Thus, the layers meld to form an essentially seamless unitary matrix having superabrasive particles therein. This continuous melded matrix improves the strength and durability of the final multi-layered tool.

As discussed in U.S. Patent No. 6,159,286, which is incorporated herein, forming the segment 10 in a plurality of thin layers provides remarkably improved control over the distribution of the diamond particles 20. By controlling the distribution of the diamond particles 20 within each layer and then combining layers, a three-dimensional segment can be formed in which distribution of the diamond particles is controlled in each dimension. This, in turn, enables the formation of segments, which are particularly adapted to the likely use of the segment, be it for polishing, cutting, grinding, etc. By tailoring the distribution and concentration of the super abrasive particles within the segment 10, more precise control is given over performance of the tool under actual working conditions.

For example, when using a diamond saw blade to cut rocks (e.g., granite), the two sides of the diamond saw segments are cutting more materials than the center. As a result of uneven wear, the cross section of the saw segment becomes convex in shape with the center bulging above both sides. This configuration typically slows the cutting rate of the saw blade. Moreover, the protruding profile may also cause the saw blade to deflect sideways in the cut slot. In order to maintain a straight cutting path, it is sometimes desirable to make a "sandwich diamond segment" to reinforce both sides of the segment with layers impregnated with more diamond or

superabrasive grits. Such a "sandwich segment" is difficult to manufacture by mixing diamond grit with metal powder by conventional means, but it can be easily accomplished by methods of the present invention: first planting diamond grits with desirable patterns and concentrations in a metal matrix layer and then assembling these metal matrix layers with diamond grits impregnated in the predetermined patterns and concentrations together to form a sandwiched segment.

The present invention further improves the above technique by infiltrating the matrix support material with a braze which is selected to chemically bond to the diamond particles and to the matrix support material. Thus, while the placement of the diamond particles shown in FIG. 6A is a marked improvement over the prior art, an additional increase in the useful life of segment 10 is obtained by utilizing a braze to form a chemical bond, rather than merely relying on mechanical retention of the diamond particles.

Likewise, the selective placement of differing sizes of diamond particles can used to form a cutting segment formed to resist premature wear to the sides of the segment, thereby extending the cutting segment's useful life. Referring specifically to FIG. 6B, there is shown a cross-sectional view of the cutting segment 10 of FIG. 6A. Unlike the cutting segments of the prior art, the cutting segment 10 is formed of three layers, 14, 16 and 18 respectively. The middle layer 16 has a plurality of super abrasive particles 20a, which are of a first size (e.g. 40/50 mesh) and a first concentration. The outer layers 14 and 18, in contrast, have a plurality of super abrasive particles 20b, which are of a second size (e.g. 50/60 mesh) smaller than the first size, and in a second concentration greater than that present in the middle layer 16. The smaller, more densely distributed super abrasive particles 20b provide the outer layers 14 and 18 with a greater resistance to wear as they cut through concrete, rock, asphalt, etc. Because the outer layers 14 and 18 are more resistant to wear, the cutting segment 10 resists formation of a convex outer surface, as has traditionally occurred with cutting elements. By maintaining a more planar cutting surface, the cutting segment is able to maintain a straight cutting path so it can cut more efficiently with a longer useful life. Moreover, by using a smaller grit on the flank of the saw, the finish of the cut surface is smoother and chipping of the workpiece can be avoided.

Furthermore, an additional increase in useful life is obtained by infiltrating the

matrix support material with a braze formed from chromium, manganese, silicon, titanium, and/or aluminum, or an alloy or mixture thereof. While a wide variety of quantities of these materials may be used, it has been found that it is preferable if the chromium, manganese, silicon, titanium, or aluminum or alloy or mixture in the diamond braze constitutes at least 3 percent of the braze by weight (and more preferably 5 percent). The braze fills the pores in the matrix support material, which is typically powder selected from the group including iron, cobalt, nickel or alloys or mixtures thereof.

Another advantage to the use of multiple layers of matrix with diamond or some other super abrasive particle disposed therein is that the layers are easily formed into other desirable shapes for the cutting, drilling, grinding, etc., segment. For example, FIG. 7A shows a perspective view of a segment, generally indicate at 30, of a super abrasive tool formed by a plurality of arcuate, longitudinal layers of matrix support material which are attached to one another to form a three-dimensional super abrasive member which has been infiltrated with the braze to thereby hold the diamond within the matrix material of the member. The segment 30 is formed from first, second and third layers, 34, 36 and 38, which are each arcuate. When the three are joined together, an arcuate segment 30 is created. Such a segment, of course, may be used on cutting tools, which are non linear, and on other types of tools for which a nonlinear superabrasive segment is desired. Because the layers 34, 36 and 38 are initially formed independent of one another, they are much easier to conform to a desired shape, and are able to do so while the brazed diamond particles 20 disposed therein are held in their predetermined positions.

Each of the layers is impregnated with a plurality of superabrasive particles 20, typically diamond or cubic boron nitride. Because each layer is a relatively thin layer of metal matrix, (i.e., the metal matrix will usually be no more than two times the thickness of the diameter of the particles), superior control over placement of the superabrasive particles in the metal matrix layer can be easily achieved. As discussed above, the random placement of superabrasives in abrasive tools in the current art often lead to ineffective use of superabrasive particles. By controlling distribution of superabrasives the present invention enables either even distribution which prevents under or over spacing, or controlled distribution so that different portions of the

segment have different sizes and concentrations which are matched to prevent traditional wear patterns.

Referring now to FIG. 7B, there is shown a cross-sectional view of a plurality of the layers 34, 36 and 38 of the segment 30. Of course, the configuration of the diamond particles may be used with the segment shown in FIG. 6A or that shown in FIG. 7A. Unlike the embodiment of FIG. 6B, the layers are each provided with the same size and concentration of the diamond particles 20. However, because the spacing is substantially uniform, there is no under spacing or over spacing between the superabrasive particles, and the segment 30 wears more evenly than the segments of the prior art with randomly spaced particles. The more even wear prevents premature failure of the segment 30, and thus extends the life of the tool while keeping the amount of superabrasive used to a minimum. Furthermore, the braze which bonds to the diamond particles and the matrix further strengthens each layer and prevents loss of the diamond particles.

FIG. 8 shows another possible embodiment of a segment 50 made in accordance with the teachings of the present invention. The layered structure in a diamond segment may also be assembled transversely or horizontally, and the braze may be applied to every layer, or to select layers as shown in FIG. 8. Thus, the segment 50 in FIG. 8 is formed from a plurality of transverse layers, generally indicated at 54. A first plurality of the layers (i.e. the first four layers), indicated at 56, are provided with a first concentration of diamond particles 20 which are brazed to bond to the matrix support material. A second plurality of layers (i.e. the remaining 9 layers), indicated at 58, are provided with a second concentration, less than the first concentration and are also brazed to bond to the matrix support material.

Many cutting tools are configured such that the cutting segment 50 is provided with a lead edge which performs a majority of the cutting and which receives most of the impact force when contacting the surface to be cut. For example, a circular saw blade will usually have a plurality of teeth or segments, each tooth having a leading edge, which takes the force of the cutting. Because the leading edge performs a significant portion of the cutting, it is much more susceptible to wear than are rotationally rearward portions of the tooth. When formed in accordance with the prior art, the teeth, however, often had relatively consistent abrasive disposed thereon. Over time the leading edge wears significantly, but the other portions coated with

diamond particles are subjected to minimal wear. Eventually, the abrasive is worn off the leading edge, while significant amounts remain on the other portions of each tooth. Thus, a considerable amount of super abrasive is wasted when the blade is discarded. The embodiment of FIG. 8 is specifically configured to overcome such concerns. The layers 56 and 58 are configured to provide substantially even wear across the cutting segment 50 by placing a larger percentage of the diamond particles 20 near the leading edge 56, than on rotationally distal portions 58. Thus, by the time the leading edge has reached the end of its useful life, the remaining portions of the cutting segment 50 have also been worn out. Such controlled distribution of the superabrasive particles 20 decreases the use of the expensive material and lowers the cost for making the cutting segment 50 without hurting performance. Additionally, by providing more ever wear, the cutting segment 50 will often be able to maintain most of its cutting speed until shortly before the end of its useful life. Additionally, brazing the diamond particles 20 in layers 56 and 58 further extends tool life.

FIG. 9 shows yet another layout of a segment wherein a three-dimensional super abrasive member is formed with progressively denser abrasive distribution toward the upper surface of a tool with horizontal layers. As with the embodiment of FIG. 8, the controlled distribution of the diamond particles 20 forms an improved abrasive segment 70, while at the same time decreasing the cost of abrasive tools by decreasing the unnecessary consumption of diamond particles. Additionally, brazing may be used on some of the layers, while being omitted from other layers, to thereby customize the abrasive segment 70.

With routine experimentation and the teachings of the method of the present invention, those skilled in the art will be able to customize cutting, drilling, grinding, polishing and other types of abrasive segments which are specifically formed to maximize their abrasive ability (i.e. cutting, drilling, grinding, etc.) over an extended useful life, while simultaneously decreasing the amount of super abrasive which is used to form the tool in accordance with the principles of the method of the present invention.

Referring now to FIGS. 10A through 10D, there is shown one method for forming layers in accordance with the principles of the present invention. Many of the same principles may be applied with respect to the formation of layered segments as to the formation of segments described in connection with FIGS. 1 through 5

above. The first step of the method is to form a sheet 100 of matrix support material 104 which will be bonded to the super abrasive particles 20. The sheet 100 of matrix support material 104 can be formed from conventional powders such as cobalt, nickel, iron, copper, bronze, or any other suitable bonding agents. Additionally, for reasons, which are discussed in detail below, it is highly advantageous to use coarse powders, such as those above 34 microns (400 mesh) in diameter. While the use of coarse powders is inconsistent with the current teachings that it is desirable to use the finest powder available, considerable benefits may be achieved by combining course powder and braze to secure diamond particles in place.

Once the sheet 100 of matrix support material 104 is formed, a template 110 is laid on the top of the sheet as shown in FIG. 10A. The template 110 contains apertures 114 that are larger than one abrasive particle 20, but smaller than two abrasive particles, thereby allowing a single particle of the abrasive to be disposed at each specific location. The thickness of the template is preferably between 1/3 to 2/3 of the height of the average abrasive particle 20. However, other thicknesses may be used if appropriate accommodations are made for seating the abrasive particles in the desired locations.

After the template 110 is properly positioned, a layer of abrasive particles 20 is then spread over the template so that each aperture 114 receives an abrasive particle. Those particles not falling into the apertures 114 in the template 110 are removed by tilting the substrate, sweeping the template with a broom, or some other similar method.

As shown in FIG. 10B, a generally flat surface 120, such as a steel plate, is then laid over the particles 20, which rest in the apertures 114 in the template 110. The flat surface 120 presses the abrasive particles 20 at least partially into the pliable sheet 100 of matrix support material 104 to seat the particles.

After removing the template 110, the flat surface 120 is used again to press the abrasive particles 120 firmly into the sheet 100 of matrix support material 104 as shown in FIG. 10C. While the flat surface 120 is preferable, those skilled in the art will appreciate that there may be occasions when it is desirable to have some of the abrasive particles 20 extend outwardly from the sheet 100 of matrix support material more that other abrasive particles. In such situations, a contoured or otherwise shaped

surface could be used to seat some of the abrasive particles 20 deeper into the sheet 100 of matrix support material 104, than other particles.

The sheets 100 may be first assembled to form the precursor of the tool segment and then hardened and finished using the infiltration and sintering techniques set forth above, or they can be hardened and finished individually, and subsequently assembled and combined to form the tool segment or the entire tool body where appropriate. Typically, the assembly of the sheets 100 is accomplished by a known method such as cold compaction with a press. The "green" body so formed can then be consolidated to form a final tool product by sintering or infiltration as described above.

If desired, the process shown in FIGS. 10A through 10C can be repeated on the other side of the sheet 100 of matrix support material 104 (as shown in FIG. 10D), to form an impregnated layer having diamond particles 20 distributed throughout the layer in some predetermined, desired pattern. The process is typically repeated several times to obtain multiple thin layers or sheets 100, which are impregnated with the diamond particles 20. Of course, each sheet 100 need not have the same distribution pattern for the diamond particles 20, nor need the concentration of the abrasive particles be the same in each sheet.

While the method described in FIGS. 10A through 10D is preferred for many applications, there are instances where it is desirable to have the abrasive particles 20 extend outwardly from the sheet 100 of matrix support material. For example, some tools may only have one layer of abrasive. This can be accomplished simply by leaving the template 110 in place when performing the steps shown in FIG. 10A and 10B, and not further pressing the particles 20 into the matrix support material once the template has been removed.

In the alternative, FIGS. 11A through 11C show a side view of an alternate to the method discussed in FIGS. 10A through 10D. The sheet 130 of matrix support material 134 in FIGS. 11A through 11C is formed to be of a lesser thickness than the cross-sectional thickness or diameter or the superabrasive particles 20. When the particles are pressed into the sheet 130, the thickness of the sheet forces the superabrasive particles 20 to protrude from the matrix support material 134. The sheet 130 is then infiltrated with diamond braze in the manner discussed above.

While the spacing of apertures of the template shown in Figure 11A through 11C is generally uniform, according to one aspect of the invention, such spacing need not be uniform, and can be according to any desired pattern. As such, variations in spacing can be provided to facilitate different concentrations on various portions to facilitate different concentrations on various portions of the sheet 130 of matrix material 134. Likewise, by controlling the size of the apertures and the order in which the diamond particles are placed in the apertures, a single layer could be provided with particles of different sizes.

In yet another alternative, FIGS. 12A through 12C show a side view of a method of forming superabrasive containing layers using sheets of amorphous braze alloy. Again, in a similar manner as previously discussed, FIG. 12A shows a template 110 having a plurality of apertures 114 arranged in a predetermined pattern, which is placed on a thin substrate or sheet of matrix support material 107. The superabrasive particles 20 are then placed in the apertures and fixed in position with an adhesive or the like. As before, the flat surface may be contoured to accommodate various tool configurations. The template 114 may then be removed. A sheet of amorphous brazing alloy 106 is then placed over the superabrasive particles 20 as shown in FIG. 12B to form a single layer segment 15. In an alternative embodiment, the sheet of amorphous brazing alloy 106 may be placed on the substrate or matrix support material layer prior to placement of the superabrasive particles thereon.

Several single layer segments 15 may then be formed and combined into a single multi-layered precursor 18, or green body, as shown in FIG. 12C. The single layer segments 15 may be secured using an adhesive as in the discussion of FIGS 6A through 6D or brazed using a traditional (i.e. does not necessarily contain a carbide former) brazing alloy. This precursor may be formed of layers of uniform distribution of superabrasive grits similar to FIG. 7B or of varying configurations, concentrations and/or particle size as in FIG. 6B. The method of the present invention includes configurations in which some of the layers are void of superabrasive particles altogether. Further, the matrix support material 107 may be a substrate layer of metal or an unsintered metal powder as described above. The resulting tool segment would have different properties depending on which type of support material is chosen.

The precursor 18 is then placed in a vacuum furnace and heated to a sufficient temperature to cause the sheet of amorphous braze alloy 106 to melt and bond to the

superabrasive particles 20 and to the layer of metal 107 to form a melded multi-layered tool having the desired pattern of superabrasive particles distributed throughout as shown in FIG. 13. FIG. 13 shows a consolidated superabrasive tool segment 19 wherein the superabrasive particles 20 are arranged in a predetermined three-dimensional pattern. The areas identified by 108 and 109 illustrate generally the pre-consolidation layers 106 and 107 of metal and braze alloy, respectively. The dotted lines are for illustrative purposes only and those skilled in the art will recognize that the actual final tool segment may differ. For example, if the sheet of braze alloy is thinner than the diameter of the particles and the metal layer is solid during the consolidation process the final tool 240 may have empty voids, or pores, 242 between particles, as shown in FIG. 16. This porosity due to the empty voids 242 may be very beneficial to the cutting action of the frame saw blade. Increased porosity may facilitate the permeation of cooling water and the removal of debris from the superabrasive tool segment. It is preferred that the porosity of the superabrasive tool segment be at least about 5%. In another aspect, the porosity may be at least about 10%.

Also, if the layer of metal is formed of unsintered powder the consolidation process will cause the final tool to be much more homogenous due to infiltration of the brazing alloy throughout the metal powder. The thickness of the layer of metal 107 and the sheet of braze alloy 106 may be of varying thickness. The thickness of the layer of metal 107 and/or the sheet of brazing alloy may be less than the diameter of the superabrasive particles 20, as shown in FIG. 12A or either may be thicker than the diameter of the superabrasive particles used. However, the thickness of the matrix support material, or substrate 107 can be selected to influence the efficiency of the cutting operation. As the superabrasive tool segment is cutting in the kerf, the superabrasive particles 20 cut grooves between ridges formed by the absence of cutting at the matrix support material, or substrate 107. If the matrix support material, or substrate 107 is thin enough, this uncut ridge will automatically break away, and the swarf will be flushed away by the cooling water. Generally speaking, for this process to occur, the matrix support material, or substrate may be less than or equal to about 1mm thick, and is preferably about 0.5mm thick or less.

During the heating process the precursor assembly is heated to just over the liquidus temperature to allow the braze alloy to flow somewhat. Maintaining the

braze alloy, and the matrix or metal layer, near the liquidus temperature helps to prevent substantial movement of the particles from their intended positions. Typically, a temperature of about 5° C above the liquidus temperature over a relatively short period of time, about 10 to about 20 minutes, is sufficient to obtain the desired results.

Referring now to FIG. 17 is shown a cross sectional view of one embodiment depicting the attachment of a superabrasive tool segment 250 to the blade member 222. The superabrasive tool segment 250 includes a plurality of matrix layers or substrates 108 arranged in a substantially parallel relationship, and each having a plurality of superabrasive particles 20 bonded thereto. As can be seen, the tool segment is brazed 254 to the cutting edge of the blade member 222. Further, two elongated matrix supports or substrates 252 may also be brazed to along at least a portion of the outer sides of the superabrasive tool segment 250, positioned flush with the sides of the blade member 222 blade member. Superabrasive particles 20 may be brazed to the exposed surfaces of the elongated matrix supports or substrates 252 for improved cutting effectiveness. Additionally, the elongated matrix supports may be brazed 256 to the sides of the blade member 222 in a conventional manner, to more firmly anchor the superabrasive tool segment 250, and thus prevent the superabrasive tool segments 250 from being knocked off by the cutting action of the frame saw 220.

C. Examples

Example 1

40/50 mesh diamond grit (SDA-85+ made by De Beers Company) were mixed with iron powders and an organic binder to form a mixture with diamond concentration of 20 (5% of total value). The mixture was cold pressed in a steel mold to form the shape of a saw segment. The precursor was placed in a graphite mold and overlaid with a powder of Nicrobraz LM. The mold was heated under vacuum to about 1,050° C for 20 minutes. The infiltrated braze had bonded diamond and matrix powder together for form a segment. Twenty-four of such segments were manufactured and they were trimmed to desirable tolerances. These segments were brazed onto a 14-inch round steel circular saw blade. The blade was used to cut granite at a faster cutting rate than was possible with conventional diamond saw blades. Additionally, the brazed saw blades had a longer useful life than a conventional diamond saw blade.

Example 2

40/50 mesh diamond grit (SDA-85$^+$ made by De Beers Company) were mixed with metal powder to form a mixture with a diamond concentration of 20 (5% of total volume). Five different proportions of cobalt (about 1.5 micrometer in size) and bronze (about 20 micrometers in size) were used for the matrix powder. An acrylic binder was added (8% by weight) to the mixture and the charge was blended to form a cake. The cake was then rolled between two stainless steel rollers to form sheets with a thickness of 1 mm. These sheets were cut in the shape of saw segments with a length of 40 mm and width of 15 mm. Three each of such segments were assembled and placed into a typical graphite mold for making conventional diamond saw segments. The assembled segments were pressed and heated by passing electric current through the graphite mold. After sintering for three minutes, the segments were consolidated to a height of 9 mm with less then 1% porosity. Twenty-four segments for each composition were fabricated. They were brazed onto a circular saw of 14 inches in diameter. These five blades were used for cutting granites and found to perform equal or better than those with higher diamond concentrations (e.g. 23) made by conventional methods. Microscopic examination of the worn segment indicated that although diamond particles were not planted into the layered matrix, they were distributed more evenly than segments prepared by the traditional method. The segregation of particles in a layered matrix was considerably less than that in the thick body of conventional segments.

Example 3

The same procedures were followed as Example 2, but with 8 thinner layers (0.4 mm) for each segment. The diamond concentration was reduced to 15 and particles were positively planted according to the illustration as shown in Figures 10A through 10D. The diamond distribution was much improved. As a result, the performance of these blades were equal or better than those made by conventional methods with diamond concentration of 20.

Example 4

Iron powdersof about 100 mesh were mixed with an S-binder made by Wall Colmonoy Company to form a cake. The cake was then rolled to form sheets of 0.4 mm in thickness. 40/50 mesh SDA-100$^+$ diamond grit was positively planted into these sheets to attain a concentration of 15. These diamond containing sheets were

cut in the shape of saw segments with a length of 40 mm and width of 9 mm. Eight of such segments were assembled as a group and placed in a graphite mold. Twenty-four groups were placed horizontally, and another twenty-four groups were placed vertically in the graphite mold. Nicrobraz LM powder (-140 mesh) (made by Wall Colmonoy Company) was added on the top of these segments. These samples were heated in a vacuum furnace (10^{-5} torr) to 1050° C for 20 minutes for horizontally placed segments, and 30 minutes for vertically placed segments. The melted LM alloy (Ni-Cr-B-Si with a liquidus point at 1000° C) infiltrated into these segments and filled the porosity. The excess LM braze on these segments were ground by electrode discharge (EDG). Each of the 24 segments so fabricated were brazed onto a 14 inch (diameter) circular saw blade. These blades were used to cut granite and showed marked improvement over conventional saw blades.

Example 5

Nicrobraz LM powder was mixed with an acrylic binder and rolled to form layers of about 0.25 mm. 40/50 mesh MBS-960 diamond grit manufactured by General Electric Company was positively planted into these metal layers according to the method as illustrated in Figure 10A through 10D. These diamond planted metal layers were cut in proper size and wrapped around 2,000 beads (pearls) of wire saw. These beads (10 mm in diameter by 10 mm long) were divided into two groups; one contains 280 crystals (about 0.2 carat). These beads were heated in a vacuum furnace to a temperature of 1,000 °C for 8 minutes. These beads were mounted on several wire saws and were used to cut marble, serpentine and granite. The performance of these beads was found to be superior to conventional beads. The latter beads were typically made by either hot pressing or electroplating. These conventional beads may contain a much higher amount of diamond (up to 1 carat) per bead.

Example 6

The same method as described by Example 5, but applied to other products, e.g., circular saws, thin-wall core bits, and curvature grounder. Each of these products shows superior performance over conventional electro-plated diamond tools having similar superabrasive concentrations.

Example 7

Mixture of metal powders that contain 87 wt% of -140 mesh Nicrobraz LM (made by Wall Colmonoy, U.S.), 8 wt% of iron of -125 mesh, and 5 wt% of copper of

-60 mesh were mixed with 3 wt% of an acrylic binder to form a dough. The dough was rolled between two rollers to form sheets of 0.6 mm thick. Each sheetwas cut to shape and covered with a template. 30/40 mesh (0.420 to 0.595 mm) diamond grits of SDA-100+ grade (made by De Beers, South Africa) were positively planted into the metal layers in a predetermined pattern with a diamond-to-diamond distance of about 2 mm. Three layers were stacked together and wrapped around a steel sleeve to form a diamond bead of 10 mm in diameter and 10 mm in length. These beads were heated in a vacuum furnace to consolidate the metal and also braze the diamond in place and onto the steel sleeve. 1,000 of such diamond beads were fitted over 5 mm steel cable that contained 7 x 19 wires, and they are spaced by plastic coating formed by injection molding. The wire was 25 meters long and it was joined end-to-end to form a loop. This wire saw was used to cut granite blocks (3.5 meter long by 1.8 meter high) of all grades. The life achieved was 0.5 square meter cut surface per diamond bead consumed (0.5 carat). This area cut is twice of that cut by conventional diamond beads made by a powder metallurgical method.

Example 8

This is the same as example 7, except many diamond impregnated layers were assembled to form a block of 20 mm long by 5 mm thick by 7 mm high. These blocks were consolidated in a vacuum furnace to form diamond segments. Each segment contained about 8 volume percent diamond. 30 of such segments were brazed onto a 4 meter long steel frame and the fame was mounted on a reciprocating sawing machine. The saw was used to cut marble blocks with a life more than twice longer than conventional diamond segments produced by powder metallurgical methods.

Example 9

This is the same as example 8, except the diamond planted layers were assembled to form segments of about 24 mm long by 3.5 mm thick for a core bits of 150 mm in diameter. The diamond content in these segments was about 4v%. 10 of such core bits were used to drill concrete. The drilling speed and the life of these core bits were much higher than conventional diamond segments made by powder metallurgical methods.

Example 10

This is the same as example 9, except the shape of segments is for circular saws. These segments were brazed to make circular saws of 230 mm (with 18

segments of 40 mm by 8.5 mm by 2.4 mm), 300 mm (with 21 segments of 50 mm by 8.5 mm by 2.8 mm), and 350 mm (with 24 segments of 50 mm by 8.5 mm by 3.2 mm) in diameter. These saws were used to cut granite, asphalt, and concrete with superior performance.

Example 11

This is the same as Example 8, except the segments are used as dressers for conditioning grinding wheels.

Example 12

A single layer of 14/16 mesh (1.4 mm to 1.2 mm in size) diamond grits (natural diamond EMB-S made by De Beers) positively planted sheet is covered over a pallet of 20 mm diameter by 8 mm thickness. Many of these pallets were brazed in a vacuum furnace. More than 3000 of such pallets were mounted on floor grinding machines to grind stone and wood floors. The results indicate that the grinding speed could be three times faster than conventional diamond grinders.

Example 13

A single layer that contained positively planted diamond grits of 40/50 mesh (0.420-0.297 mm size) ISD 1700 grade (made by Iljin Diamond of Korea) was laid over the curved surface of a profile wheel and brazed to form a rigid tool in a vacuum furnace. More than 100 of such profile wheels of various diameters were used to form the edges of granite and marble slabs. These profile wheels were capable to cut more than 3 times faster than conventional diamond tools made by either electroplating or sintering method.

Example 14

This is the same as example 13, except that the diamond planted layer is wrapped around a steel sleeve to form a single layered diamond beads. More than 100,000 of such beads were manufactured. They were used to cut granite or marble with superior performance.

Example 15

This is the same as example 12, except the diamond grits were 80/100 mesh, and the diamond planted layer was used to cover the surface of a flat disk of 4 inches in diameter. 4 such disks were produced and used as conditioner to dress the CMP (chemical and mechanical polishing) pad that polished silicon wafers. The result

indicated that the CMP efficiency was much improved and the conditioner outlasted conventional conditioners made by either electroplating or brazing.

Example 16

Wall Colmonoy's Nicrobraz LM powder is used as the braze. It is mixed with either iron powder (Fe), copper powder (Cu), or both in various proportions (the following refer to the weight percentage of the overall mixture): 90LM/10SiC; 90LM/10WC; 100LM; 92LM/8Fe; 90LM/10Cu; 82LM/8Fe/10Cu; 80LM/20Cu; 72LM/8Fe/20Cu; 70LM/30Cu; and 60LM/40Cu. The mixture also contains 4 weight percent of an acrylic binder that is used to glue all powder together. The mixture is cold pressed to form a sheet and heated to 400°C for 30 minutes in air to burn out most of the organic binder. The preform is then placed in a vacuum oven maintained at a pressure of 10^{-5} torr. Heating is applied to a temperature of 1010°C for 12 minutes. After the LM was completely melted and has infiltrated (or metal sintered by the aid of molten LM) the solid metal powder the consolidated mass is cooled. After cooling the consolidated mass is taken out of the oven and tested for hardness and abrasion resistance. It is discovered that the HRB hardness for these compositions are 140, 130, 120, 118, 116, 110, 108, 100, 100, and 70, respectively. The abrasion resistance is decreases in the same order.

The hardness or abrasion resistance is important, as it must match the wear rate of diamonds in a tool so the grit can be exposed to the proper height for cutting a work piece efficiently. When an abrasive material, such as diamond particles, is bonded to a soft matrix it may become over exposed. As a result, the abrasive material may be shattered or dislodged during the cutting action thus reducing the tool life.

It has been determined based on these experiments that diamond bonded on a 92LM/8Fe matrix is most suitable to cut hard materials such as concrete, granite, and sandstone. A 80LM/20Cu matrix is more suitable to cut softer materials such as limestone and marble.

Example 17

Diamond grits of 30/40 mesh (SDA-100+ of De Beers Company) were mixed with an 80LM/20Cu matrix. Various cutting tools containing 30 concentration diamonds (about 8 volume percent) were produced. Tools included circular saw segments, gang saw segments, and wire saw beads which were then brazed to circular

saw blades, reciprocatively cutting gang saw blades, and steel cables respectively. Although somewhat random, these tools were used to saw a variety of rocks with long lives and high cutting rates.

Example 18

This is an example of sintering solid braze powder together without the melting step. LM powder was mixed with either Fe, Cu, or both in various proportions and an acrylic binder (4 weight percent) to form a dough. The dough was then rolled using steel rollers to form sheets 1 mm thick. 30/40 (18 concentration) and 40/50 (22 concentration) diamond grits of SDA-100+ were positively planted into these sheets using a template that contained holes of proper size in fixed positions. These sheets were cut to a size of 40 mm long by 8 mm wide. Five of these cut sheets were stacked together with three center layers that contained 30/40 mesh diamond. The assembly was hot pressed in a graphite mold at 400 atm and 900°C. After cooling, the segments were brazed onto circular steel blades. The blades with matrices containing 80LM/20Cu and 80LM/10Fe/10Cu performed satisfactorily.

Example 19

In this example single layer diamond forms are brazed directly onto the substrate for making a pad conditioner. LM powder is mixed with 4 weight percent of acrylic binder to form a malleable dough. The dough is rolled between two steel rolls to form a layer 0.2 mm thick. 80/90 mesh diamond grits of IMD-H as manufactured by Iljin Diamond Company was used to plant into the sheet. The planting was guided by a template that fixed the diamond to diamond distance as 0.7 mm. The diamond planted LM layer is then trimmed in size and glued using an organic binder to a flat stainless (316) plate 6.5 mm thick. The assembly is then heated in vacuum to 1010°C for 10 minutes. The heating caused the LM to melt and bond to the substrate. The finished diamond disk is used as a pad conditioner that dressed the pad during the chemical and mechanical planarization (CMP) of silicon wafers. The result indicates that such diamond disk can double the life when compared to a conventional diamond disk that contains randomly distributed diamond grits.

Example 20

This is the same as Example 19, except the Nicrobraz LM powder is 140 mesh.

Example 21

Nicrobraz LM powder of 325 mesh is mixed with Nicrobraz S binder to form a slurry. The slurry is then sprayed onto 100 round stainless steel pallets of 20 mm in diameter and 8 mm thickness to form a thin coating. The spraying processis repeated until a thickness of 0.15 mm was achieved. After the coating is dried, a template with holes drilled to form a square grid with a distance of 0.5 mm between holes is placed on the substrate. 100/120 mesh diamonds are then placed on the substrate to form the predetermined grid pattern. The template is then removed leaving the diamond particles adhered to the surface. The binder is then removed by heating in an oven in air at 200° C for 2 hours. The assembly is then heated in a vacuum to 1,005° C for 10 minutes. During this process, the molten braze has wetted the diamond and capillary force has pulled down the diamond particles to touch the substrate. The results are diamond pallets with diamond firmly brazed to form a wetting slope and these diamond crystals form a predetermined pattern of grid. The resulting tool is well suited for use in CMP applications.

Example 22

This is the same as example 12, except that the slurry is a ready made product supplied by Wall Colmonoy as NICRO-SPRAY.

Example 23

This is the same as example 12, except the slurry is prepared by suspending NICROBRAZ LN powder in a methanol benzene solution containing Nanbau resin (manufactured in Taiwan).

Example 24

The braze is provided as a sheet of amorphous braze alloy manufactured by Honeywell as MBF-20 foil about 0.001" thick. Various sizes are punched out of the foil and glued to round stainless steel substrate. A template is then used to arrange 80/90 mesh diamond particles in a predetermined grid pattern. The assembly is then dewaxed and heated in a vacuum furnace to melt the alloy and bond the diamond to the substrate. The final tool is used as a pad conditioner for CMP applications. The resulting tool demonstrates that the polishing rate can be sustained much longer than conventional pad conditioners. Further, defects on the semiconductor wafers is greatly reduced.

Example 25

The braze is provided as a sheet of amorphous braze alloy manufactured by Honeywell as MBF-20 foil, having a thickness of 0.002". Annular sections 100 mm in diameter having 50 mm holes at the center are punched out of the foil. A template is then placed on the annular ring of amorphous braze and 60/80 mesh diamond particles are sprinkled over the template surface. The excess diamonds are removed and then the template is removed leaving the diamonds particles set in a predetermined pattern. An additional annular ring is glued on the top of these diamond particles. Six of such amorphous alloy-diamond amorphous alloy sandwiches are assembled with a stainless ring of the same size but with a thickness of 0.1 mm between every two of such layers. An acrylic adhesive is used to glue the assembly together. The final assembly is then heated to 200° C for 2 hours to drive off the adhesive. The assembly is then heated in a vacuum furnace at 1,005° C for 15 minutes. The resulting tool is a three dimensional structure that contains a diamond array not just on surface but also in volume. This three dimensional structure is then mounted to a chuck with a shaft for use as a grinding wheel. Such a ginding wheel has the unique feature of containing connected pores around diamond. These pores can serve as runways for removing cutting debris. The openness of this grinding wheel makes it free cutting so the cutting speed is about twice that of conventional grinding wheels. Conventional grinding wheels using metal as matrix contains no such interconnected pores.

A distinct advantage cutting tools of the present invention have over the prior art cutting tools lies in the manner in which the tool may be used. Diamond saws are typically made in the form of a circular blade that cuts the workpiece by rotation in the same direction with each rotation. This one directional movement causes a "tail" to be formed, wherein the matrix material rotationally forward of the diamond particle is worn away, but the matrix material behind the diamond particle is protected by the diamond particle. If the saw rotation were to be reversed, the diamond particle would easily be knocked free of the matrix.

Round saws, however, can only cut the work piece to a depth of less than one-half the diameter of the saw. In order to cut thicker workpieces, a frame or gang saw is typically used. Because these saws move reciprocally, the diamond particles must be securely held on each side. As a result, tails of diamond matrix cannot be

maintained to hold the diamond particles in place. It is for this reason that reciprocating diamond saws have not been used to cut hard rock such as granite. Rather they are used to cut only soft materials such as marble.

This invention allows diamond to be held chemically by a braze. Hence, matrix tails are not needed to support the diamond. As a result, tools made according to the present invention can be used on reciprocating saws to cut hard materials. This breakthrough can expand diamond applications to markets, which were previously unavailable due to limitations of the prior art.

In addition to being able to improve the performance of the tool and to reduce the cost of manufacturing, this invention also provides an easier method for making thin bladed tools. For example, the electronic industry requires using larger and larger silicon wafers (now 12 inches in diameter). Hence, thinner saw blades for slicing silicon crystals, and thinner dicing wheels for grooving silicon chips with tighter partitions have been in great demand.

Prior to the present invention, it has been extremely difficult to make very thin tools that contain evenly distributed diamond particles. The present invention provides an alternative method for making such tools. For example, it has been discovered that by mixing micron powders of diamond, a blend of metal powders (e.g., bronze and cobalt) and a suitable binder, the material can be rolled to a thickness thinner than 0.1 mm - a thickness which is thinner than most dicing wheels. By firing this thin sheet and mounting it on a tool holder, a thin dicing wheel can be made.

In the alternative to the above, it has been found in accordance with the present invention that some of the advantages of the controlled distribution, multilayered superabrasive configurations described above can be achieved without the use of a template. More specifically, the abrasive particles can also be mixed in with the matrix powder and made as an ingredient of the layered sheet. In this case, the distribution of abrasive particles is still somewhat random. Even so, their distribution is typically more uniform than that in a conventional abrasive body. The segregation of abrasive particles and matrix powders discussed in the background section is less extensive in a substantially two-dimensional sheet than in a three-dimensional body. This is particularly true for sheets made by a deforming process

(e.g., by rolling). In this case, abrasive particles are further spread out in the matrix by the shearing action of the rollers.

This invention may also be applicable to other applications not related to making abrasive tools. For example, graphite or metal sheets planted with diamond particles may be used as seeds for diamond growth under high pressure and temperature. Industrial diamonds are typically produced by compressing alternative layers of graphite and metal catalyst (e.g., Fe, Co, or Ni alloy) to high pressure and heating above the melting point of the catalyst. Diamond will then nucleate randomly on the interface of these layers. The quality of the diamond crystal formed often suffers by the impingement of growing crystals that are distributed unevenly. Hence, the yield and cost of diamond synthesis can be substantially improved by making the nuclei uniformly distributed. This invention can provide layers of either graphite or metal catalyst with a pre-determined pattern of diamond seeds. If organic binders are introduced during the fabrication of these layers, they can be removed by heating in a furnace before loading into the press.

It is to be understood that the above-referenced arrangements are illustrative of the application for the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function, manner of operation, assembly, and use may be made without departing from the invention as set forth in the claims.